

Flat and Uphill Climb Time Trial Performance Prediction in Elite Amateur Cyclists

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Abstract

The aim of this study was to determine physiological, anthropometric, biomechanical and hormonal variables related to road flat and uphill climb performance. Eighteen elite level amateur road cyclists (21.1 ± 3.8 yrs), homogeneous with regard to time trial performance (coefficient of variation: 2.9–5.2%), were measured for frontal area (FA), maximal strength, power, cross-sectional area of the quadriceps femoris muscle and basal serum concentrations of total testosterone (TT), free testosterone (FT) and cortisol (C). Maximal (W_{\max}) and submaximal workload were measured during a progressive discontinuous maximal cycling laboratory test, and two all-out time trial performance tests (duration range: 1049–1251 s) were also conducted outdoors on two separate days: a 14-km flat road (average gradient of 0.2%) and a

6.7-km uphill climb (average gradient of 6%). Significant negative correlations ($p < 0.01$ – 0.001) were observed between the individuals' 14-km flat time values and the individual values of W_{\max} ($r = -0.90$) and FA ($r = -0.73$). Regression analysis showed that the individual values of the 6.7-km uphill climb trial performance time correlated significantly ($p < 0.05$ – 0.001) with those of FT ($r = -0.75$) and $W_{\max} \cdot \text{kg}^{-1}$ ($r = -0.66$). The present results suggest that flat time trial performance in highly elite amateur cyclists is mainly related to absolute maximal workload and anthropometric variables, whereas uphill climb time trial performance is associated with maximal workload normalized to body mass, as well as with an increased anabolic-androgenic activity.

Key words

Maximal workload · body size · hormones · heart rate · lactate

Introduction

Road cycling success is mainly dependent on the ability to optimize competition requirements in individual flat time trial and high mountain passes. Previous studies have described terrain-related differences in physiological variables and anthropometric characteristics during stage races in professional road cyclists [21,25]. Because of this, screening of appropriate physiological and anthropometric demands in each competition terrain and subsequent identification for performance prediction is critically important.

Several studies have examined the relationship between anthropometric as well as laboratory data and cycling outdoor time trial

performance over short (~20–35 minutes), flat road [1,8,18,23] or uphill climb [9] distances. These studies have reported a significant relationship between maximal power output (W_{\max}) or maximal oxygen uptake ($\dot{V}O_{2\max}$) obtained from an incremental test to exhaustion and flat road time performance ($r = -0.46$ to -0.91). However, the subjects participating in these prediction cycling flat road studies were not very homogeneous in cycling performance time and can not be considered as elite competitive road cyclists [22]. The limited studies of uphill cycling [3,9] have also used low-level cyclists with a high range of cycling abilities. Likewise, no studies have simultaneously examined the relationships between laboratory variables and flat road as well as uphill climb performance in elite competitive amateur road cyclists.

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The existence in elite amateur male cyclists of high absolute maximal strength values in the lower extremity [13] and low resting subclinical levels of serum testosterone [12] has previously been reported. The high maximal strength values have been related to an asynchronous activation and recruitment of FT fibers that occur during submaximal cycling [20] and, particularly, to the short bursts of extremely high instantaneous power outputs of 800–1000 W that are interspersed between longer periods of cycling at submaximal intensities [15]. It has been suggested that reduced basal serum testosterone concentrations are partially related to dysfunction of the hypothalamic-pituitary-testicular axis due to altered central stimulation of the gonads and suppressed testicular ability to produce testosterone [7]. However, to the best of our knowledge, no previous studies have investigated how such high muscular strength values and suppressed testicular function could affect short-term performance in elite amateur cyclists.

Accordingly, the primary purpose of this cross-sectional study was to determine the relationship among anthropometric, cycling laboratory test, flat road and uphill climb outdoor performance in elite amateur road cyclists. Additionally, we hypothesized that differences in muscular strength and in basal anabolic status may affect cycling performance.

Methods

Subjects

Eighteen male elite amateur road cyclists volunteered to participate in this study (mean age 21.1 ± 3.8 yrs). The elite amateur road cyclists belonged to two cycling teams ranked among the best five Spanish national amateur teams. They won more than 25 one-day races and four 4–6-day races during the following competitive season. At the end of that season, 6 of the 18 road cyclists turned professional. The cyclists were tested between February and March, that is, 10 days before the beginning of the competitive season. At the time of testing, they had already cycled between approximately 5000 and 9000 km in training. They cycled $350\text{--}660\text{ km}\cdot\text{wk}^{-1}$ (between 11 and 21 hours $\cdot\text{wk}^{-1}$) and between 18000–26000 km in a season, adding up training and competition distances.

The subjects were informed carefully about the experiment procedures and about the possible risks and benefits of the project, which had been approved by the Institutional Review Committee of the Instituto Navarro de Deporte y Juventud (Navarra, Spain), and carried out according to the Declaration of Helsinki. Subjects were not taking any medication that would affect their physical performance. They were not taking exogenous anabolic-androgenic steroids or other drugs or substances expected to affect physical performance or hormonal balance for several months before or during this study, nor were they on any medication that would impact the results of the study.

Experimental design

This cross-sectional study was separated into 3 testing sessions: a laboratory session and two field road sessions. The subjects reported to the laboratory on days 1 and 2 to obtain measurements of anthropometric variables, muscle strength and power testing,

muscle cross-sectional area, resting blood samples, and a cycling laboratory test. On day 6, the subjects performed the maximal time trial tests on the uphill road. On day 8, the subjects performed the maximal time trial tests on the flat road. During the first testing session, subjects reported to the laboratory after a 12-hour overnight fast to give a resting blood sample for analysis and measure the cross-sectional area of the quadriceps femoral muscle group. In addition, the subjects performed the strength test and the cycling laboratory test. They were asked not to participate in vigorous training or competition during the 2 days before the arrival at the laboratory and to ingest a normal but CHO-rich diet. All subjects undertook the second testing session on the same day within 4–5 days after the completion of the first testing session. The purpose of the second testing session was to complete a 6.7-km uphill climb time trial. The third testing session was performed two days after the uphill climb road tests and after one day of minimal physical training. The purpose of the third session was to complete a 14-km flat road time trial. All subjects undertook the flat road test on the same day. All experiments were always performed in the morning. During the week of the performance evaluation, the subjects' training and diet were standardized. All subjects were familiarized with the laboratory and field road time trials protocols as they had been previously tested in the laboratory with the same testing procedures and they had been competing on several flat roads and uphill climb time trials in previous years. No repeated testing could be performed because the study was undertaken during the unique 7-day team stage of the season. However, it has been shown that the predictor time trial test in elite athletes is highly reliable, representing a good simulation of the competitive events [11].

Anthropometric variables

Body surface area (BSA, in m^2) was estimated based on the following formula by Du Bois and Du Bois [4]:

$$\text{BSA} = 0.007184 \cdot \text{BM}^{0.425} \cdot \text{H}^{0.725}$$

in which BM is body mass (in kg) and H is the height of the cyclist (in cm). Assuming that frontal area (FA) can be considered proportional to BSA, and based on previously measured values [24], the value of FA was considered to be 18.5% of BSA. The percentage of adipose tissue in the body was estimated from seven skinfold thickness [14].

Maximal strength and muscle power testing

The subjects were carefully familiarized with the testing procedure of voluntary force production during several submaximal and maximal actions a few days before the measurements. The subjects also completed several explosive type actions to become familiar with the action required to move different loads rapidly. In addition, several warm-up muscle actions were recorded prior to the actual maximal actions.

Maximal strength of the lower extremity muscle was assessed using one repetition concentric maximum (1RM) half-squat action. In the half-squat (1 RM_{HS}), the shoulders were in contact with the bar and the starting knee angle was 90° . On command, the subject performed a concentric leg extension (as fast as possible) starting from the flexed position to reach the full extension of 180° against the resistance determined by the weight plates

added to both ends of the bar. The trunk was kept as straight as possible. A weight-training belt was used by all subjects. All the tests were performed in a squatting apparatus in which the barbell was attached to both ends, with the linear bearings on two bars allowing only vertical movements. Warm-up consisted of a set of 5 repetitions at the loads of 40–60% of the estimated maximum. Thereafter, four to five separate single attempts were performed until the subject was unable to extend the legs to the required position. The last acceptable extension with the highest possible load was determined as 1RM. The rest period between the actions was always 2 minutes.

The power-load relationship of the leg extensor muscles was also tested in a half-squat position using the relative loads of 15%, 30%, 45%, 60%, 70%, 80% and 100% of 1RM, respectively. In this case, the subjects were instructed to move the load as fast as possible. Two testing actions were recorded and the best reading (with the highest velocity) was taken for further analyses. The rest period between each trial and set was always 1.5 minutes.

During the test actions, bar displacement, average velocity ($m \cdot s^{-1}$) and mean power (W) were recorded by linking a rotary encoder to the end of the bar. The rotary encoder recorded the position and direction of the bar to an accuracy of 0.0002 m. Customized software (JLML I + D, Madrid, Spain) was used to calculate the power output for each repetition of the half-squat performed throughout the whole range of motion. Average power output for each repetition of the half-squat was determined. Average power was calculated throughout the whole range of motion used to perform a complete repetition. Averaged indexes of muscle power were calculated as the average of the power values obtained under all experimental conditions of the half-squat performance. The reproducibility of the measurements of maximal strength and muscle power output was assessed on 2 trials separated by 7 days in eleven weightlifters as subjects in a pilot study. No significant differences were observed between the 2-days measurements. The intertest ICC ranged from 0.65 to 0.95, the coefficient of variation (CV) between 4.7% and 7.9% and r from 0.57 to 0.98, respectively [12].

In all the neuromuscular performance tests, strong verbal encouragement was given to each subject to motivate them to perform each test action as maximally and as rapidly as possible. The rest period between each trial and set was always 1.5 and 3 minutes, respectively.

Muscle CSA

Cross-sectional area (CSA) of the quadriceps femoral (QF) muscle group (rectus femoris, vastus lateralis, vastus medialis and vastus intermedialis; CSA_{QF}) was measured with a compound ultrasonic scanner (Toshiba SSA-250, Tokyo, Japan) and a 5 MHz convex transducer. The CSA was measured at the lower third portion between the greater trochanter and lateral joint line of the knee. Two consecutive measurements were taken from the right thigh and then averaged for further analyses. CSA was then calculated from the image by the computerized system of the apparatus. Muscle CSA showed reliability coefficients of 0.85. The coefficient of variation ranged from 1.4% to 4.3% for the measured circumference and cross-sectional area of the quadriceps femoris (CSA_{QF}) muscle group, respectively.

Cycling laboratory test

Each subject performed a maximal multistage discontinuous incremental cycling test on an electromagnetic cycle ergometer (Orion, S.T.E., Toulouse, France) adapted with a racing saddle, drop handlebars and clip-in pedals, at a constant pedalling cadence of 85 rpm. The electromagnetic cycle ergometer is a specific ergometer for well-trained cyclists, allowing them to adapt individually to create the same position as in competition. The validity of this ergometer has been described elsewhere [12]. The subjects started with a workload of $1 W \cdot kg^{-1}$ body mass lasting 3 minutes, with the load being increased by $1 W \cdot kg^{-1}$ body mass, every 3 minutes until volitional exhaustion. After each workload, the test was interrupted for 60 seconds prior to initiating the next workload. Exhaustion was defined as the subject not being able to maintain the required pedalling cadence. Heart rate was monitored continuously using a heart rate monitor (Vantage NV Polar, Kempele, Finland) and determined during the last 60 seconds of each stage. Subjects were verbally encouraged during the test.

Capillary blood samples for the determination of lactate concentrations were obtained from a hyperemic earlobe before the exercise and immediately after each exercise stage. Samples for whole blood lactate determination (100 μ l) were deproteinized, stored at 4 °C, and analyzed within 5 days of completing the test. The blood lactate analyzer (YSI 1500, Yellow Springs, Ohio, USA) was calibrated after every fifth blood sample with three known controls (5, 15 and 30 $mmol \cdot l^{-1}$). Individual data points for the exercise blood lactate values were plotted as a continuous function against time. The exercise lactate curve was fitted with a second-degree polynomial function. The range of the individual correlation coefficient with the use of the mathematical function described above was $r = 0.98–0.99$ ($p < 0.001$). The workloads associated with blood lactate concentration of 1.5 $mmol \cdot l^{-1}$ above the baseline ($W_{+1.5}$), 2 $mmol \cdot l^{-1}$ (W_2), and 4 $mmol \cdot l^{-1}$ (W_4) were interpolated from the equation describing the exercise blood lactate curve. W_2 and W_4 have been shown to be important determinants of endurance performance capacity [29]. The maximal workload reached by each cyclist's test (W_{max}) was calculated according to the following formula:

$$W_{max} = W_{com} + ([t \cdot 180^{-1}] \cdot \Delta W)$$

in which W_{com} is the last workload completed, t the number of seconds in the final and incomplete stage sustained, and ΔW the final load increment [16].

Road time trials

Each subject participated in a 6.7-km uphill climb time trial (6.7 km UTT) and a 14-km flat time trial (14 km FTT) on two outdoor roads on two separate days. Fig. 1 shows the course profile in altitude against road distance covered during the uphill climb and the flat time trials. On the first time trial day, the subjects were instructed to ride the 6.7-km UTT (Fig. 1a) (average gradient of 6%). On the day of the UTT test, the mean ambient temperature was 10 °C and there was light rain.

Two days after the 6.7-km UTT, the subjects were instructed to ride a 14-km FTT on a straight traffic-free road circuit of 7 km, with an average gradient of 0.2% (Fig. 1b). Subjects completed

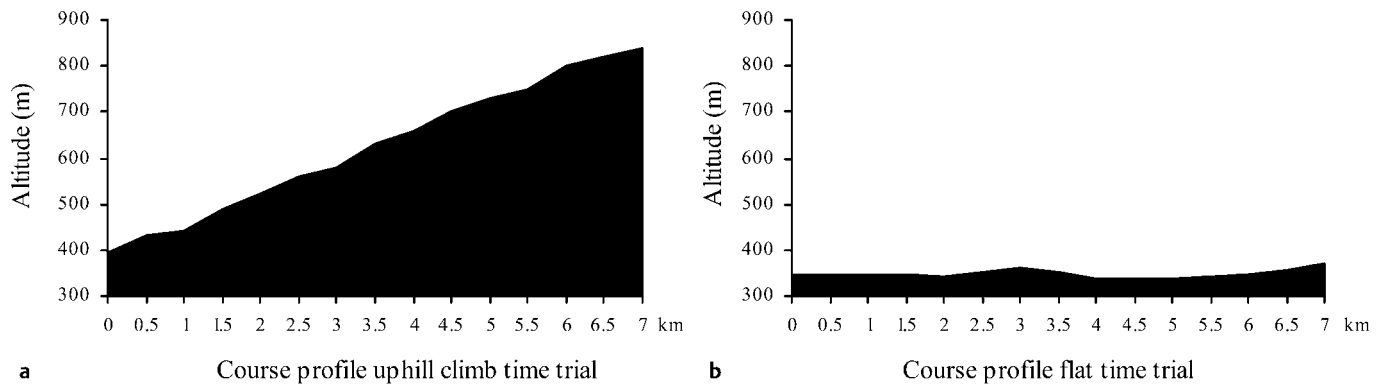


Fig. 1 Course profile in altitude against road distance covered for both the uphill climb time trial (6.7 km and average gradient of 6%) and flat time trial (14 km and average gradient of 0.2%).

two lengths of this course (a total of 14 km). Turnaround times were included and were generally under 30 s. On the day of the test, the mean temperature was 14°C and there was little to no wind. The time to complete the course was recorded to the nearest second. Three cyclists could not ride the FTT test due to disease or injuries.

After each time trial, capillary blood samples for the determination of lactate concentrations were obtained from a hyperemic earlobe immediately, and at 3 minutes postexercise. Heart rate was recorded continuously from a heart monitor (Vantage NV Polar, Kempele, Finland). The cyclists began both individual time trials from a supported standing start at 2-minute intervals. In both trials, subjects were allowed to select the pace and pedal at a self-selected rate in order to complete the ride in the shortest possible time while producing a maximal effort. The subjects completed both trials with no reference to time. All subjects had standard, modern, lightweight, and well-maintained bicycles. During the time trial tests, disc wheels, aerodynamic bars and drafting were not allowed.

Blood hormones

Venous blood samples were obtained from the antecubital vein at rest between 8–9 a.m. to determine concentrations of serum total testosterone, free testosterone, and cortisol. The samples were centrifuged and the serum removed and frozen at -20°C for later analysis. The serum cortisol and testosterone assays were performed by radioimmunoassay. Serum total testosterone (T), free testosterone (FT) and cortisol (C) concentrations were measured using reagent kits from Diagnostic Product Corporation and INCSTAR Corporation (Coat-A-Count total/free testosterone TKTTT11CS, Los Angeles, CA, USA; and GammaCoat cortisol radioimmunoassay kit, Los Angeles, CA, USA). The sensitivity of the total testosterone and free testosterone assay was $0.14\text{ nmol}\cdot\text{l}^{-1}$ and $0.15\text{ }\mu\text{g}\cdot\text{ml}^{-1}$, respectively. The sensitivity of the cortisol assay was $0.21\text{ }\mu\text{g}\cdot\text{dL}^{-1}$. The coefficient of intra-assay variation was 5.1% and 4.2% for the total and free testosterone, respectively. The respective value for the cortisol assay was 6.6%. All samples were analyzed in the same assay for each hormone, according to the instructions of the manufacturer.

Statistical methods

Standard statistical methods were used for the calculation of the mean and standard deviations and coefficients of variation. Pearson product-moment correlation coefficients (r), the standard error of estimate (SEE) and the 95% confidence limits (95% CL) for each Pearson correlation coefficient were calculated to determine the association between physiological variables and time trial tests. In addition, a stepwise multiple linear regression analysis was used to predict 6.7-km UTT and 14-km FTT. The independent variables (FT, W_{max} , $W_{+1.5}$ and frontal area) that correlated most significantly with the 6.7-km UTT and 14-km FTT were entered into the stepwise procedure. One-way ANOVA with repeated measures (condition “within subjects” factors) was used for statistical analyses. In the case of a significant F value, the Scheffé post hoc test for multiple comparisons was used to assess differences between means. Student’s t -tests were used to evaluate differences between subgroups. The $p < 0.05$ criterion was used for establishing statistical significance. All data are expressed as means \pm SD.

Results

Anthropometric variables and serum hormone concentrations

Mean (\pm SD) body mass, percent body fat, and frontal area were $71.1 \pm 6.2\text{ kg}$, $5.8 \pm 1.0\%$ and $0.35 \pm 0.02\text{ m}^2$, respectively. The concentrations of serum total testosterone, free testosterone and cortisol are presented in Table 1. Serum hormone concentrations were within normal clinical levels (between 10.4 and $38.2\text{ nmol}\cdot\text{l}^{-1}$ for total testosterone, between 31 and $153\text{ }\mu\text{mol}\cdot\text{l}^{-1}$ for free testosterone, and between 193 and $690\text{ nmol}\cdot\text{l}^{-1}$ for cortisol), except in two subjects for total testosterone (7.0 and $7.6\text{ nmol}\cdot\text{l}^{-1}$), one subject for free testosterone ($30.2\text{ }\mu\text{mol}\cdot\text{l}^{-1}$), and three subjects for cortisol concentrations (709 , 739 and $831\text{ nmol}\cdot\text{l}^{-1}$).

Muscle CSA, muscle strength, and muscle power output

The mean (\pm SD) CSA of QF was $52.1 \pm 3.2\text{ cm}^2$. The results of the maximal bilateral concentric 1 RM_{HS} , expressed in absolute terms, relative to kilograms of body mass ($\text{kg}\cdot\text{kg}^{-1}$), and CSA_{QF} ($\text{kg}\cdot\text{cm}^{-2}$), were $134 \pm 18\text{ kg}$, $1.89 \pm 0.28\text{ kg}\cdot\text{kg}^{-1}$ and $2.57 \pm 0.37\text{ kg}\cdot\text{cm}^{-2}$, respectively. At all absolute loads examined, power output index

Table 1 Anthropometric variables and serum hormone concentrations of the cyclists. Values are expressed as means \pm SD

Variable	Mean \pm SD
Height (cm)	181.3 \pm 16.1
Body mass (kg)	71.1 \pm 6.2
Body fat (%)	5.8 \pm 1.0
Body surface area (m ²)	1.9 \pm 0.12
Frontal area (m ²)	0.35 \pm 0.02
Testosterone (nmol·l ⁻¹)	18.1 \pm 5.4
Free Testosterone (pmol·l ⁻¹)	75.1 \pm 26.1
Cortisol (nmol·l ⁻¹)	544.6 \pm 132.5
Testosterone/cortisol ratio	0.04 \pm 0.01
Free Testosterone/cortisol ratio	0.15 \pm 0.07

of the lower extremities was 397 ± 99 W and maximal power output of the lower extremities was produced at the load of 45% (498 ± 110 W) of 1 RM_{HS}.

Cycling laboratory exercise and road time trial tests

During the cycling laboratory test, the average maximal workload (W_{\max}) was 490 ± 56 W and the value of maximal workload relative to body mass ($W_{\max} \cdot \text{kg}^{-1}$) was 6.9 ± 0.4 W·kg⁻¹, whereas the elapsed time during the 6.7-km uphill climb time trial (UTT) and the 14-km flat time trial (FTT) was 1115 ± 59 s (18.6 ± 1.0 min; 21.6 ± 1.2 km·h⁻¹), and 1185 ± 35 s (19.8 ± 0.6 min; 42.5 ± 1.3 km·h⁻¹), respectively. The coefficients of variation (SD \times 100/average) for W_{\max} , $W_{\max} \cdot \text{kg}^{-1}$, UTT time, and FTT time were 11.4%, 5.8%, 5.2% and 2.9%, respectively. During the cycling laboratory test, the submaximal workloads associated with blood lactate concentrations of 1.5 mmol·l⁻¹ above baseline ($W_{+1.5}$), 2 (W_2), and 4 (W_4) mmol·l⁻¹ were 335 ± 38 W, 326 ± 39 W and 389 ± 42 W, respectively.

The maximal blood lactate concentration of 11.7 ± 1.6 mmol·l⁻¹, recorded after the cycling laboratory test, was significantly higher ($p < 0.01$) than that recorded after UTT (9.4 ± 2.3 mmol·l⁻¹) and FTT (8.7 ± 2.2 mmol·l⁻¹). The maximal heart rate of 190 ± 7 beats·min⁻¹ recorded after UTT was significantly lower ($p < 0.01$) than that recorded after the cycling laboratory test (194 ± 8 beats·min⁻¹) and FTT (193 ± 8 beats·min⁻¹).

Prediction a of 6.7-km UTT from laboratory and road variables

The individual values of the 6.7-km UTT time correlated negatively ($r = -0.66$; $p < 0.01$; SEE of 46 s; 95% CL -0.88 and -0.22) with the individual values of maximal workload relative to body mass ($W_{\max} \cdot \text{kg}^{-1}$) (Fig. 2), as well as with the individual values of $W_{+1.5}$, W_4 , and W_5 relative to body mass ($W_{+1.5} \cdot \text{kg}^{-1}$, $W_4 \cdot \text{kg}^{-1}$, $W_5 \cdot \text{kg}^{-1}$) (from $r = -0.55$ to -0.60 ; $p < 0.05$) attained during the cycling laboratory test. When maximal or submaximal power output obtained during laboratory conditions were normalized to body mass raised to the power of 0.79–0.89 or to the bike weight added to the body mass, the correlation coefficients of the uphill cycling performance were not stronger. The individual values of

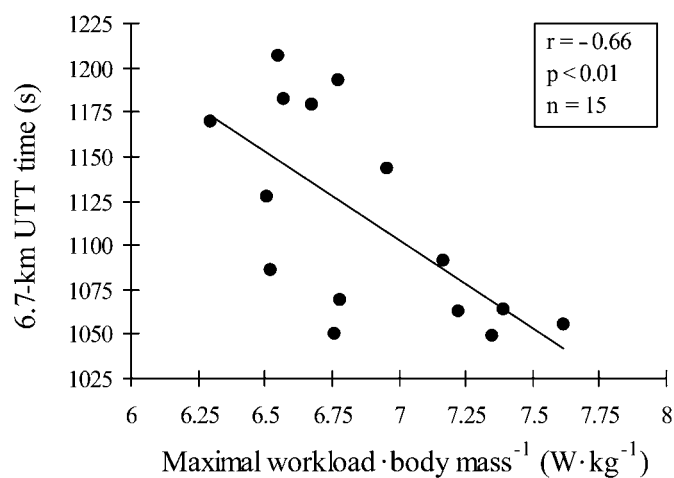


Fig. 2 The relationship between the 6.7-km uphill climb time trial time (6.7-km UTT) values and the maximal workload relative to body mass attained during the cycling laboratory test.

the 6.7-km UTT time correlated negatively ($r = -0.75$; $p < 0.001$; SEE of 41 s; 95% CL -0.91 and -0.39) with the individual values of basal serum free testosterone concentration (Fig. 3), as well as with the individual values of serum total testosterone and the serum free testosterone/cortisol ratio ($r = -0.57$ to -0.61 ; $p < 0.05$). Interestingly, compared to the subgroup of cyclists with the fastest uphill cycling performance ($n = 8$), those with the slowest uphill cycling performance ($n = 7$) showed 43% lower concentrations of basal serum free testosterone (55.3 ± 20 pmol·l⁻¹ vs. 95.9 ± 19 pmol·l⁻¹; $p < 0.01$) and serum free testosterone/cortisol ratio (0.105 ± 0.04 vs. 0.186 ± 0.07 ; $p < 0.05$). The stepwise multiple linear regression analysis with the 6.7-km UTT time as a dependent variable, and the individual values of serum free testosterone concentration, W_{\max} and $W_{+1.5}$ relative to body mass as independent variables, showed that serum free testosterone concentration and W_{\max} relative to body mass as a two factor combination predictor, accounted for 78% of the performance variance.

Prediction of a 14-km FTT from laboratory and road variables

The individual values of the 14-km FTT time correlated negatively with the absolute individual values of maximal workload (W_{\max}) ($r = -0.90$; $p < 0.001$; SEE of 16 s; 95% CL -0.97 and -0.72 ; Fig. 4) and maximal workload relative to the frontal area ratio ($r = -0.78$; $p < 0.05$), $W_{+1.5}$ ($r = -0.80$; $p < 0.001$), and W_4 ($r = -0.85$; $p < 0.001$) attained during the cycling laboratory test. When maximal or submaximal power output, obtained during laboratory conditions, was normalized to body mass raised to the power of 0.32, the correlation coefficients of level cycling performance were not stronger. In addition, the individual values of the 14-km FTT time correlated positively with individual values of the frontal area relative to body weight ($r = 0.61$; $p < 0.05$), but negatively with the individual values of frontal area ($r = -0.73$; $p < 0.01$) and body mass ($r = -0.74$; $p < 0.01$).

No significant correlations were observed between the individual values of both road time trials and the individual values of maximal strength or muscle power.

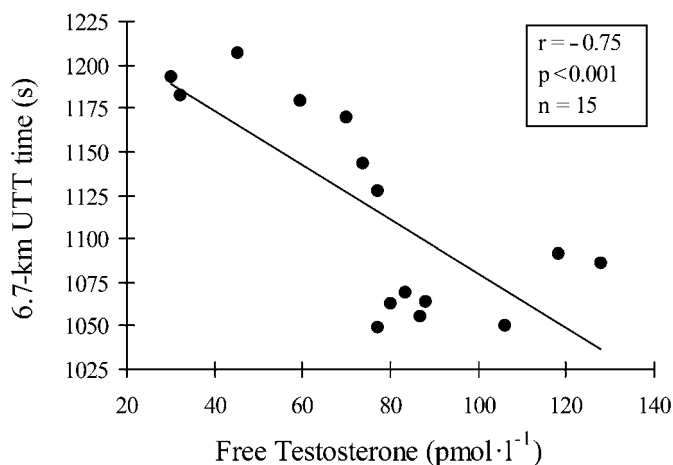


Fig. 3 The relationship between the 6.7-km uphill climb time trial (6.7-km UTT) values and the individual basal values of serum free testosterone concentration attained during the cycling laboratory test.

Discussion

The salient findings of the present study were as follows: first, in the short-distance flat road time trial performance, absolute maximal workload during a cycling laboratory test and anthropometric variables are related to the performance in this type of event; second, in the short-distance uphill climb trial performance, serum free testosterone concentration and W_{\max} relative to body mass as a two factor combination predictor, accounted for 78% of the performance variance. The present study is the first to suggest that elite cycling-related reductions in serum testosterone concentration affect performance.

The average relative W_{\max} values recorded in the present study ($6.9 \text{ W} \cdot \text{kg}^{-1}$) are considered as a prerequisite for top-level competitive cyclists ($> 5.5 \text{ W} \cdot \text{kg}^{-1}$) [21,25]. Although the well-recognized limitation associated with the different cycling procedures used in this and previous studies make comparison difficult, the cyclists in the present study showed similar average relative maximal power output ($6.9 \text{ W} \cdot \text{kg}^{-1}$ versus $6.0\text{--}7.3 \text{ W} \cdot \text{kg}^{-1}$, respectively) [10,21,25] and peak blood lactate concentration ($6.9\text{--}13.7 \text{ mmol} \cdot \text{l}^{-1}$) [25] compared to those reported in professional road cyclists. On the other hand, submaximal workloads (expressed in percentage of W_{\max}) that elicited a blood lactate concentration of $4 \text{ mmol} \cdot \text{l}^{-1}$ recorded in the present cyclists were slightly lower than in international professional road cyclists (79% versus 84–90% of W_{\max} , respectively) [10,25]. In addition, the present cyclists were very homogeneous with regard to flat (CV: 2.9%) and uphill (CV: 5.2%) time performance. Taken together, the present results indicate that our subjects can be considered as highly and homogeneous elite amateur competitive road cyclists [21].

An important finding of the present study is the strong negative correlation observed between the time in a 14-km road flat trial and the maximal workload attained during the cycling laboratory test (W_{\max}) ($r = -0.90$; $p < 0.001$), which is an accurate predictor of maximal oxygen uptake [8]. Our result is consistent with previous flat road cycling time trial studies ranging from 15 to 40 km but performed ($r = -0.84$ to -0.91) [8,17] with more

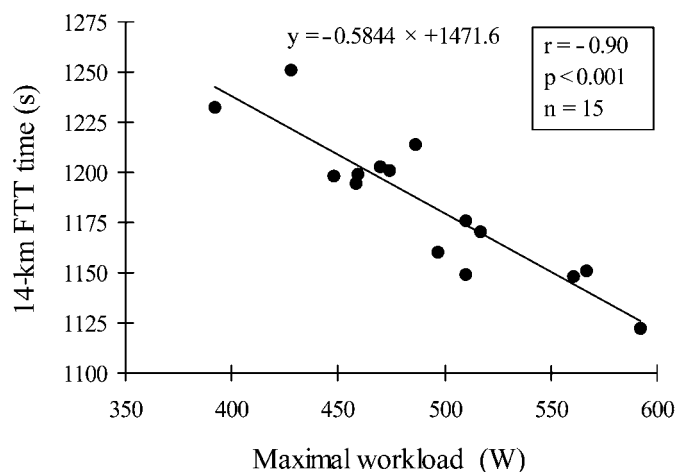


Fig. 4 The relationship between 14-km flat time trial time (14-km FTT) values and the absolute maximal workload values attained during the cycling laboratory test.

heterogeneous groups (CV: 6.4–11%) [8,17,24] of lower level cyclists [8,18], showing that absolute W_{\max} is a better performance predictor than other physiological variables [8]. In the present study, we extended our investigation by determining the relation between W_{\max} and flat road performance in highly trained elite amateur road cyclists. Indeed, the strong association between W_{\max} and the flat trial time occurred within a small range in cycling abilities (CV: 2.9%). This suggests that absolute W_{\max} is a good physiological parameter for short-course (~20 minutes) flat cycling performance in a very homogeneous elite amateur cyclist population, and might differentiate among flat road performers.

It has been documented that the best professional flat road time trial specialists tend to be larger and heavier than uphill specialists [21,25]. In our homogeneous highly elite amateur cyclists, a negative correlation between body mass and the time in the 14-km flat trial was observed. Additionally, flat road performance correlated negatively with frontal area relative to body mass. Taken together, these data are consistent with the notion that the advantage of larger cyclists in time trials conducted on flat courses is principally due to reductions in their energy expenditure relative to body mass [27] and their lower frontal area to body mass ratio, allowing them to reduce air resistance more effectively [25,27].

Significant negative correlations were observed in the present study between the individual time in a 6.7-km uphill climb trial and the individual maximal workload (W_{\max}) relative to body mass, as well as the individual concentration of basal serum free testosterone. Significant negative correlations between uphill climb time and W_{\max} relative to body mass has also been reported in cyclists in similar [3,9] or longer [9] distances during outdoor road [9] or simulated treadmill hill climbing tests [3]. The higher negative correlations observed in these studies ($r = -0.71$ to -0.97) compared with our results can be explained by the fact that the previous studies used cyclists with a lower cycling level ($W_{\max} \cdot \text{BM}^{-1} < 5.5 \text{ W} \cdot \text{kg}^{-1}$) and a higher range of cycling abilities (CV: 7–10%) than in the present study. Thus, the present results are in line with previous findings observed in top-level profes-

sional cyclists, suggesting that a high power output:body mass ratio is a necessary prerequisite to compete successfully in uphill cycling events [3,21,25].

Owing to the cross-sectional design of the study, the interpretation based on the results of serum hormones should be treated with great caution. The results of the regression analysis showed, however, that serum free testosterone concentration and W_{\max} relative to body mass, as a two-factor combination predictor, accounted for 78% of the performance variance in the 6.7-km uphill climb trial. Under the limitations associated with the use of resting hormonal concentrations, the present results suggest that the combination of both factors, W_{\max} relative to body mass and basal serum free testosterone, are good predictors of uphill cycling performance in elite cyclists.

Consistent with previous studies in elite endurance runners [7,30] and professional cyclists [10,19], we recently reported a lower basal total and free testosterone concentration in the present elite amateur cyclists versus sedentary age-matched controls [12]. Although the physiological mechanisms underlying the reduced basal testosterone concentration in the endurance-trained are uncertain, it has been suggested they are related to hypervolemia, loss of body mass, and/or low dietary fat usually observed in cyclists [5,28,30]. In addition, a number of studies have reported that the lower basal hormone concentrations in endurance-trained men is due, at least in part, to a dysfunction of the hypothalamic-pituitary-testicular axis, which is mediated by altered central stimulation of the gonads [7] and suppressed testicular ability to produce testosterone [2,7,10,19]. Thus, Hackney et al. [7] have recently reported a suppressed basal testosterone production rate following GnRH infusion in endurance trained men with lower basal serum testosterone levels than sedentary controls. To the best of our knowledge, no previous studies have investigated how such suppressed testicular function could affect performance in elite amateur cyclists. A unique finding in the present study was that the subgroup of 7 cyclists with the slowest uphill cycling performance ($n=7$) showed 43% lower concentrations of basal serum free testosterone and serum free testosterone/cortisol ratio compared to the subgroup of 8 cyclists with the fastest uphill cycling performance. This indicates that basal low serum free testosterone concentrations included within normal clinical levels are associated with decreased cycling performance. Whether the decreased uphill cycling performance is due to a transient condition limited to this particular group of subjects or it is due to reduced muscle glycogen, protein, creatine phosphate synthesis [5,6,26], and/or increased cortisol production [2], which are associated with low testosterone production, this cannot be discerned through the present study. The present findings do not support the speculation that reduced serum testosterone levels in endurance trained men could be a beneficial training adaptation [2].

Few studies have measured maximal strength and power values of the lower extremity in elite amateur road cyclists. In a previous personal study [13], absolute maximal strength and muscle power production at the load of 30% of 1RM in half-squat actions were significantly greater in the present cyclists than in middle distance runners and sedentary age-matched control men. It has been suggested [13] that a plausible explanation of

this training-specific adaptation could be related to the similar average times of force application during the concentric actions (for example, at a load of 30% of 1RM half-squat it was 560 ms) and the downstroke portion of the pedal stroke at the pedalling rates preferred by the cyclists (90 rpm). Based on this, it was presumed that differences in muscle strength and power during half-squat actions would partially affect cycling performance. However, none of the selected muscular strength or power variables reliably predicted uphill or flat road performance. The present results suggest that maximal strength and muscle power in the lower limbs during half-squat actions do not represent a limitation for further short-course performance in homogeneous elite amateur cyclists. However, this finding should be interpreted with caution since: 1) it is possible that a minimum level of maximal strength or muscle power in the lower limbs must be reached to be successful in road cycling, and 2) a more specific power measurement during a brief cycling sprint might predict differences in short course cycling performance.

In summary, our study represents an attempt to characterize the physiological demands that account for flat and uphill road performance in elite amateur competitive road cyclists. The current results indicate that absolute maximal workload during a cycling laboratory test and the anthropometric variables, at least in part, are the best predictors for short-course (~20 minutes) flat road cycling performance. Furthermore, uphill performance is associated with maximal workload relative to body mass, as well as with high anabolic hormonal level. Finally, the clinical implications associated with the decline in the anabolic-androgenic activity observed in our elite amateur road cyclists warrant further investigation.

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